

# **DRAG REDUCTION IN MICROFLUIDIC**

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## ABSTRACT

Frictional force is an unavoidable problem in transportation in pipeline which will cause a great pressure drop in the pipeline. Currently, industries use pumps to maintain the pressure in the pipeline for transportation. In order to solve this problem, researchers were developing drag reduction technique using different types of materials to get an alternative for pumps. Drag reduction is a technique where a minute amount of drag reduction additives, usually parts per million (ppm), is added into liquid which reduce the frictional drag greatly. However, researches are mostly done in macroscale where there will be a waste in reagent. In this experimental study, investigation the effect of variable concentration of nanopowders with different size of microchannels and different flow rate on drag reduction is carried out. The nanopowder (Bismuth (III) oxide, Iron (II,III) oxide, Silica and Titanium (IV) oxide) is dissolved in DI water and the fluid is pumped into microchannels with the width and depth of 50  $\mu\text{m}$ , 100  $\mu\text{m}$  and 200  $\mu\text{m}$  respectively which is connected to pressure transmitter through syringe pump. Nanopowder is an effective drag reduction additive with the drag reduction up to more than 64%. It is believed that Iron (II, III) oxide is the most effective DRA.

## ABSTRAK

Daya geseran adalah masalah yang tidak dapat dielakkan dalam pengangkutan dalam perancangan yang akan menyebabkan penurunan tekanan besar dalam perancangan. Kini, industri menggunakan pam untuk mengekalkan tekanan dalam perancangan untuk pengangkutan. Penyelidik telah membangunkan teknik pengurangan seretan menggunakan pelbagai jenis bahan untuk mendapatkan alternatif untuk pam. Pengurangan seretan adalah satu teknik di mana sedikit jumlah bahan pengurangan seretan, biasanya bahagian per juta (ppm), ditambah ke dalam cecair yang memberi impak yang besar kepada pengurangan seretan. Walau bagaimanapun, kebanyakan kajian dijalankan dalam sistem makro yang akan menghasilkan banyak bahan buangan. Dalam kajian eksperimen ini, penyiasatan kesan kepekatan *nanopowders* dengan saiz *microchannels* dan kadar aliran pada pengurangan seretan dijalankan. *Nanopowder* ini (Bismut (III) oksida, Ferum (II, III) oksida, Silika dan Titanium (IV) oksida) dilarutkan dalam air DI dan cecair dipam ke dalam *microchannels* yang mempunyai dimensi 50µm, 100µm dan 200µm yang disambungkan kepada pemancar tekanan melalui pam picagari. *Nanopowder* adalah bahan pengurangan seretan yang berkesan dengan pengurangan seretan mencapai lebih daripada 64%. Ferum (II, III) oksida adalah dipercayai merupakan bahan pengurangan seretan yang paling berkesan.

## TABLE OF CONTENTS

SUPERVISOR’S DECLARATION .....	IV
STUDENT’S DECLARATION .....	V
Dedication.....	VI
ACKNOWLEDGEMENT .....	VII
ABSTRACT.....	VIII
ABSTRAK.....	IX
TABLE OF CONTENTS .....	X
LIST OF FIGURES.....	XII
LIST OF TABLES .....	XVI
LIST OF ABBREVIATIONS.....	XX
LIST OF ABBREVIATIONS.....	XXI
1 INTRODUCTION.....	1
1.1 Motivation and statement of problem .....	1
1.2 Objectives .....	2
1.3 Scope of this research.....	2
1.4 Main contribution of this work .....	2
1.5 Organisation of this thesis .....	2
2 LITERATURE REVIEW .....	4
2.1 Introduction.....	4
2.2 Drag Reduction in Microchannels .....	5
2.2.1 Soluble Additives.....	5
2.2.2 Insoluble Additives .....	7
2.3 Summary.....	7
3 MATERIALS AND METHODS .....	8
3.1 Raw Materials .....	8
3.1.1 Transported Liquid.....	8
3.1.2 Chemicals .....	8
3.2 Nanopowder solution preparation .....	8
3.3 Equipments .....	9
3.3.1 Microchannels.....	9

3.3.2	Syringe Pump.....	9
3.3.3	Pressure Transmitter.....	10
3.3.4	Microscope .....	10
3.3.5	Volumetric flask and Pipette .....	11
3.3.6	Hot Plate and Magnetic Stirrer .....	11
3.4	Experimental set-up.....	11
3.5	Experimental Procedure .....	12
3.6	Summary.....	13
4	RESULTS AND DISCUSSIONS .....	14
4.1	Overview .....	14
4.2	Results .....	14
4.2.1	Effect of Concentration .....	14
4.2.2	Effect of Type of Nanopowders.....	20
4.2.3	Effect of Microchannel Size .....	28
4.3	Discussions .....	38
4.3.1	Effect of concentration .....	38
4.3.2	Effect of Type of Nanopowders.....	38
4.3.3	Effect of Microchannel Size .....	39
4.4	Summary.....	39
5	CONCLUSION AND RECOMMENDATIONS .....	40
5.1	Conclusion .....	40
5.2	Recommendations and Future work.....	40
	REFERENCES .....	41
	APPENDIX A .....	46
	APPENDIX B .....	47
	APPENDIX C .....	77
	APPENDIX D.....	78
	APPENDIX D-1: Effect of Concentration.....	78
	APPENDIX D-2: Effect of Type of Nanopowders .....	82
	APPENDIX D-3: Effect of Microchannel Size .....	87

## LIST OF FIGURES

Figure 2-1: Schematic diagram of the experiment for DR using polyacrylamide-based polymer.....	5
Figure 2-2: Experimental set up for measuring pressure drop for the experiment of DR using polymer and surfactants additives in liquid flow.....	7
Figure 3-1: Syringe pump.....	9
Figure 3-2: Pressure Transmitter.....	10
Figure 3-3: Microscope .....	10
Figure 3-4: Hot Plate .....	11
Figure 3-5: Schematic Diagram of experimental apparatus .....	12
Figure 3-6: Flow Diagram for Experimental Work .....	13
Figure 4-1: Variations of %DR with different concentration of Titanium (IV) Oxide using 50 $\mu$ m .....	14
Figure 4-2: Variations of %DR with different concentration of Titanium (IV) Oxide using 100 $\mu$ m .....	15
Figure 4-3: Variations of %DR with different concentration of Titanium (IV) Oxide using 200 $\mu$ m .....	15
Figure 4-4: Variations of %DR with different concentration of Bismuth (III) Oxide using 50 $\mu$ m .....	16
Figure 4-5: Variations of %DR with different concentration of Bismuth (III) Oxide using 100 $\mu$ m .....	16
Figure 4-6: Variations of %DR with different concentration of Bismuth (III) Oxide using 200 $\mu$ m .....	17
Figure 4-7: Variations of %DR with different concentration of Silica using 50 $\mu$ m.....	17
Figure 4-8: Variations of %DR with different concentration of Silica using 100 $\mu$ m.....	18
Figure 4-9: Variations of %DR with different concentration of Silica using 200 $\mu$ m.....	18
Figure 4-10: Variations of %DR with different concentration of Iron (II, III) Oxide using 50 $\mu$ m .....	19

Figure 4-11: Variations of %DR with different concentration of Iron (II, III) Oxide using 100 $\mu$ m .....	19
Figure 4-12: Variations of %DR with different concentration of Iron (II, III) Oxide using 200 $\mu$ m .....	20
Figure 4-13: Variations of %DR with different nanopowders of 100ppm using 50 $\mu$ m	20
Figure 4-14: Variations of %DR with different nanopowders of 100ppm using 100 $\mu$ m .....	21
Figure 4-15: Variations of %DR with different nanopowders of 100ppm using 200 $\mu$ m .....	21
Figure 4-16: Variations of %DR with different nanopowders of 200ppm using 50 $\mu$ m	22
Figure 4-17: Variations of %DR with different nanopowders of 200ppm using 100 $\mu$ m .....	22
Figure 4-18: Variations of %DR with different nanopowders of 200ppm using 200 $\mu$ m .....	23
Figure 4-19: Variations of %DR with different nanopowders of 300ppm using 50 $\mu$ m	23
Figure 4-20: Variations of %DR with different nanopowders of 300ppm using 100 $\mu$ m .....	24
Figure 4-21: Variations of %DR with different nanopowders of 300ppm using 200 $\mu$ m .....	24
Figure 4-22: Variations of %DR with different nanopowders of 400ppm using 50 $\mu$ m	25
Figure 4-23: Variations of %DR with different nanopowders of 400ppm using 100 $\mu$ m .....	25
Figure 4-24: Variations of %DR with different nanopowders of 400ppm using 200 $\mu$ m .....	26
Figure 4-25: Variations of %DR with different nanopowders of 500ppm using 50 $\mu$ m	26
Figure 4-26: Variations of %DR with different nanopowders of 500ppm using 100 $\mu$ m .....	27
Figure 4-27: Variations of %DR with different nanopowders of 500ppm using 200 $\mu$ m .....	27

Figure 4-28: Variations of %DR of 100ppm Titanium (IV) Oxide at different flow rates .....	28
Figure 4-29: Variations of %DR of 200ppm Titanium (IV) Oxide at different flow rates .....	28
Figure 4-30: Variations of %DR of 300ppm Titanium (IV) Oxide at different flow rates .....	29
Figure 4-31: Variations of %DR of 400ppm Titanium (IV) Oxide at different flow rates .....	29
Figure 4-32: Variations of %DR of 500ppm Titanium (IV) Oxide at different flow rates .....	30
Figure 4-33: Variations of %DR of 100ppm Bismuth (III) Oxide at different flow rates .....	30
Figure 4-34: Variations of %DR of 200ppm Bismuth (III) Oxide at different flow rates .....	31
Figure 4-35: Variations of %DR of 300ppm Bismuth (III) Oxide at different flow rates .....	31
Figure 4-36: Variations of %DR of 400ppm Bismuth (III) Oxide at different flow rates .....	32
Figure 4-37: Variations of %DR of 500ppm Bismuth (III) Oxide at different flow rates .....	32
Figure 4-38: Variations of %DR of 100ppm Silica at different flow rates .....	33
Figure 4-39: Variations of %DR of 200ppm Silica at different flow rates .....	33
Figure 4-40: Variations of %DR of 300ppm Silica at different flow rates .....	34
Figure 4-41: Variations of %DR of 400ppm Silica at different flow rates .....	34
Figure 4-42: Variations of %DR of 500ppm Silica at different flow rates .....	35
Figure 4-43: Variations of %DR of 100ppm Iron (II, III) Oxide at different flow rates	35
Figure 4-44: Variations of %DR of 200ppm Iron (II, III) Oxide at different flow rates	36
Figure 4-45: Variations of %DR of 300ppm Iron (II, III) Oxide at different flow rates	36
Figure 4-46: Variations of %DR of 400ppm Iron (II, III) Oxide at different flow rates	37



Figure 4-47: Variations of %DR of 500ppm Iron (II, III) Oxide at different flow rates 37

## LIST OF TABLES

Table 3-1: The physical properties of nanopowder chosen .....	8
Table 4-1: The maximum %DR achieved by DRA .....	39
Table B- 1: Pressure Drop for concentration of 500ppm in 50 $\mu\text{m}$ channel size .....	47
Table B- 2: Pressure Drop for concentration of 500ppm in 100 $\mu\text{m}$ channel size .....	48
Table B- 3: Pressure Drop for concentration of 500ppm in 200 $\mu\text{m}$ channel size .....	49
Table B- 4: Pressure Drop for concentration of 400ppm in 50 $\mu\text{m}$ channel size .....	50
Table B- 5: Pressure Drop for concentration of 400ppm in 100 $\mu\text{m}$ channel size .....	51
Table B- 6: Pressure Drop for concentration of 400ppm in 200 $\mu\text{m}$ channel size .....	52
Table B- 7: Pressure Drop for concentration of 300ppm in 50 $\mu\text{m}$ channel size .....	53
Table B- 8: Pressure Drop for concentration of 300ppm in 100 $\mu\text{m}$ channel size .....	54
Table B- 9: Pressure Drop for concentration of 300ppm in 200 $\mu\text{m}$ channel size .....	55
Table B- 10: Pressure Drop for concentration of 200ppm in 50 $\mu\text{m}$ channel size .....	56
Table B- 11: Pressure Drop for concentration of 200ppm in 100 $\mu\text{m}$ channel size.....	57
Table B- 12: Pressure Drop for concentration of 200ppm in 200 $\mu\text{m}$ channel size.....	58
Table B- 13: Pressure Drop for concentration of 100ppm in 50 $\mu\text{m}$ channel size .....	59
Table B- 14: Pressure Drop for concentration of 100ppm in 100 $\mu\text{m}$ channel size.....	60
Table B- 15: Pressure Drop for concentration of 100ppm in 200 $\mu\text{m}$ channel size.....	61
Table B- 16: Drag Reduction for concentration of 500ppm in 50 $\mu\text{m}$ channel size .....	62
Table B- 17: Drag Reduction for concentration of 500ppm in 100 $\mu\text{m}$ channel size .....	63
Table B- 18: Drag Reduction for concentration of 500ppm in 200 $\mu\text{m}$ channel size .....	64
Table B- 19: Drag Reduction for concentration of 400ppm in 50 $\mu\text{m}$ channel size .....	65
Table B- 20: Drag Reduction for concentration of 400ppm in 100 $\mu\text{m}$ channel size .....	66
Table B- 21: Drag Reduction for concentration of 400ppm in 200 $\mu\text{m}$ channel size .....	67
Table B- 22: Drag Reduction for concentration of 300ppm in 50 $\mu\text{m}$ channel size .....	68
Table B- 23: Drag Reduction for concentration of 300ppm in 100 $\mu\text{m}$ channel size .....	69

Table B- 24: Drag Reduction for concentration of 300ppm in 200µm channel size .....	70
Table B- 25: Drag Reduction for concentration of 200ppm in 50µm channel size .....	71
Table B- 26: Drag Reduction for concentration of 200ppm in 100µm channel size .....	72
Table B- 27: Drag Reduction for concentration of 200ppm in 200µm channel size .....	73
Table B- 28: Drag Reduction for concentration of 100ppm in 50µm channel size .....	74
Table B- 29: Drag Reduction for concentration of 100ppm in 100µm channel size .....	75
Table B- 30: Drag Reduction for concentration of 100ppm in 200µm channel size .....	76
Table C- 1: Calculation for the Reynolds Number for the microchannel size of 50µm .	77
Table C- 2: Calculation for the Reynolds Number for the microchannel size of 100µm	77
Table C- 3: Calculation for the Reynolds Number for the microchannel size of 200µm	77
Table D- 1: % DR for Titanium (IV) Oxide in 50µm microchannel size .....	78
Table D- 2: % DR for Titanium (IV) Oxide in 100µm microchannel size .....	78
Table D- 3: % DR for Titanium (IV) Oxide in 100µm microchannel size .....	78
Table D- 4: % DR for Bismuth (III) Oxide in 50µm microchannel size.....	79
Table D- 5: % DR for Bismuth (III) Oxide in 100µm microchannel size.....	79
Table D- 6: % DR for Bismuth (III) Oxide in 200µm microchannel size.....	79
Table D- 7: % DR for Silica in 50µm microchannel size.....	80
Table D- 8: % DR for Silica in 100µm microchannel size.....	80
Table D- 9: % DR for Silica in 200µm microchannel size.....	80
Table D- 10: % DR for Iron (II, III) Oxide in 50µm microchannel size .....	81
Table D- 11: % DR for Iron (II, III) Oxide in 100µm microchannel size .....	81
Table D- 12: % DR for Iron (II, III) Oxide in 200µm microchannel size .....	81
Table D- 13: % DR of 100ppm nanopowder in 50µm microchannel size .....	82
Table D- 14: % DR of 100ppm nanopowder in 100µm microchannel size .....	82
Table D- 15: % DR of 100ppm nanopowder in 200µm microchannel size .....	82
Table D- 16: % DR of 200ppm nanopowder in 50µm microchannel size .....	83

Table D- 17: % DR of 200ppm nanopowder in 100 $\mu\text{m}$ microchannel size .....	83
Table D- 18: % DR of 200ppm nanopowder in 200 $\mu\text{m}$ microchannel size .....	83
Table D- 19: % DR of 300ppm nanopowder in 50 $\mu\text{m}$ microchannel size .....	84
Table D- 20: % DR of 300ppm nanopowder in 100 $\mu\text{m}$ microchannel size .....	84
Table D- 21: % DR of 300ppm nanopowder in 200 $\mu\text{m}$ microchannel size .....	84
Table D- 22: % DR of 400ppm nanopowder in 50 $\mu\text{m}$ microchannel size .....	85
Table D- 23: % DR of 400ppm nanopowder in 100 $\mu\text{m}$ microchannel size .....	85
Table D- 24: % DR of 400ppm nanopowder in 200 $\mu\text{m}$ microchannel size .....	85
Table D- 25: % DR of 500ppm nanopowder in 50 $\mu\text{m}$ microchannel size .....	86
Table D- 26: % DR of 500ppm nanopowder in 100 $\mu\text{m}$ microchannel size .....	86
Table D- 27: % DR of 500ppm nanopowder in 200 $\mu\text{m}$ microchannel size .....	86
Table D- 28: % DR for 100ppm Titanium (IV) Oxide.....	87
Table D- 29: % DR for 200ppm Titanium (IV) Oxide.....	87
Table D- 30: % DR for 300ppm Titanium (IV) Oxide.....	87
Table D- 31: % DR for 400ppm Titanium (IV) Oxide.....	88
Table D- 32: % DR for 500ppm Titanium (IV) Oxide.....	88
Table D- 33: % DR for 100ppm Bismuth (III) Oxide .....	88
Table D- 34: % DR for 200ppm Bismuth (III) Oxide.....	89
Table D- 35: % DR for 300ppm Bismuth (III) Oxide.....	89
Table D- 36: % DR for 400ppm Bismuth (III) Oxide.....	89
Table D- 37: % DR for 500ppm Bismuth (III) Oxide .....	90
Table D- 38: % DR for 100ppm Silica.....	90
Table D- 39: % DR for 200ppm Silica.....	90
Table D- 40: % DR for 300ppm Silica.....	91
Table D- 41: % DR for 400ppm Silica.....	91
Table D- 42: % DR for 500ppm Silica.....	91

Table D- 43: % DR for 100ppm Iron (II, III) Oxide .....	92
Table D- 44: % DR for 200ppm Iron (II, III) Oxide .....	92
Table D- 45: % DR for 300ppm Iron (II, III) Oxide .....	92
Table D- 46: % DR for 400ppm Iron (II, III) Oxide .....	93
Table D- 47: % DR for 500ppm Iron (II, III) Oxide .....	93

## LIST OF ABBREVIATIONS

$u$	velocity
$d$	diameter
$\Delta P$	Pressure drop
$N_{Re}$	Reynolds Number

### *Greek*

$\rho$	density
$\mu$	dynamic viscosity

### *Subscripts*

$a$	after drag reducing additive addition
$b$	before drag reducing additive addition

## **LIST OF ABBREVIATIONS**

DR	Drag reduction
DRA	Drag reduction additives
DRP	Drag reduction polymers
%DR	Drag reduction efficacy

# 1 INTRODUCTION

## 1.1 *Motivation and statement of problem*

With the development of economy around this world, energy resources are greatly utilized. The main energy resources in this world now are petroleum and natural gas. Transportation of petroleum and natural gas are essential to transport the natural resources from the upstream to downstream for refining. However, transportation of the petroleum and natural gas faces some problem such as frictional forces which causes great energy losses across the long pipelines.

In order to overcome the great energy losses across the pipelines, pumps are installed to increase back the pressure of the fluids in pipes. The installation of pump systems increase the utility cost in the term of purchase, installation and maintenance costs. Besides that, pumps also consumed large amount of energy that is electrical energy.

An alternative method has to be used to maintain the energy and pressure of the fluid and also reduce the utility cost and energy consumption. Since 1970, pipeline drag reduction (DR) technology has been developed to increase the bottom-line profit especially in oil and gas industry [1]. Toms was the first to publish DR data in 1949 where he reported the unusual low friction factor after adding poly(methyl methacrylate) in monochlorobenzene. This is later named as “Toms effect” [2]. Toms effect is commercially utilized in USA Alaskan pipeline to increase flow transportation efficiency and reduce drag which reported in 1982 [3].

However, lots of wastes are produced while doing these researches since large amount of reagents is used in the macroscale researches. To overcome the problems, this work aims to do the research in microscale by using microfluidic devices. This can reduce the waste of chemicals and fluids which may cause hazard to the environment and even the health of living things. By using microfluidic devices, the time for the preparation of sample and measurement will be reduced greatly by up to two orders of magnitude [4].

In addition, different types of nanopowders are chosen to be used in this research to investigate the relationship of molecular weight, size and concentration of



additives to drag reduction. Effect of the flow rate and the channel size of microchannel on the drag reduction also will be investigated.

## ***1.2 Objectives***

The following are the objectives of this research:

- To investigate the addition of nanopowder on the DR performance using microfluidic devices
- To investigate the effect of molecular weight, size and concentration of nanopowder on the DR performance.
- To investigate the flow rate of the solution and channel size of microchannels on the DR performance.

## ***1.3 Scope of this research***

The following are the scope of this research:

- i) Experimental study using microfluidic technique
- ii) Experimental study on DR performances using different types of nanopowder
- iii) Experimental study on DR performances varying concentration, flow rate and channel size

## ***1.4 Main contribution of this work***

The following are the contributions:

- i) understand the effect of different parameters on the DR performance
- ii) enhanced DR hence reduce the cost in pumping system in chemical industries

## ***1.5 Organisation of this thesis***

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 provides a review of the DR researches done before. In this chapter also reviews on DR in microfluidic using different drag reduction additives (DRA's) such as polymers and surfactants.

Chapter 3 gives a description of the methodology of this research work including the chemicals and equipments use.

Chapter 4 presents the results of this experiment. In this chapter also presents the discussion for the results obtained from experimental work.

Chapter 5 draws together a summary of the thesis and outlines the future work which might be derived from the model developed in this work.

## 2 LITERATURE REVIEW

### 2.1 Introduction

Drag reduction (DR) is a technique where a minute of drag reducing additives (DRA's) are added, usually part per million (ppm) to reduce the energy losses along the flow [3]. Since 1970, pipeline drag reduction technology has been developed to increase the bottom-line profit especially in oil and gas industry [1]. Toms was the first to publish drag reduction data in 1949 where he reported the unusual low friction factor after adding poly(methyl methacrylate) in monochlorobenzene. This is later named as "Toms effect" [2]. Toms effect is commercially utilized in USA Alaskan pipeline to increase flow transportation efficiency and reduce drag which reported in 1982 [3, 5]. Since then, several types of drag reducing agents (DRA's) such as polymers [6-10] and surfactants [11-16] were introduced and tested for different industrial applications [17-21].

Conventionally, researches on DR are done in pipes where the time of preparation is long and the amount of reagents used is significant thus contribute to environmental problems. Recently, microfluidic was adopted as one of the economically feasible techniques in validating the DR effects of many new additives [22-24] to solve the problems caused by doing researches in pipes. Microfluidic is a technique to handle a small volume of fluid within the microfluidic devices, named microchannel. There are many advantages using microchannels especially in research field. These include only small amount of reagent are needed, reduce the waste hence is more environmental friendly, more precise in handling the fluid, accuracy and efficiency increases and more economic [22, 25, 26]. Besides application in DR, there is a wide range of application for microfluidic including chemistry and biological assay [27]. Functional elements such as mixers, reactors, sensors and separators in microfluidic have also developed [28]. Microfluidic devices have been used for the research on the smart drug delivery [29, 30] and used in medical diagnostic and biosensors [31]. The treatments now for cancer are surgery and radiation and chemotherapy which will kill healthy cells and cause toxicity to patient. In order to solve this problem, Paul Ehrlich proposed that drugs should be released at the affected area. A review published by I.U Khan et al about cancer targeted drug delivery

systems by microfluidic suggested that drug delivery using microfluidics should be developed to synthesis drug carriers [32].

## 2.2 Drag Reduction in Microchannels

### 2.2.1 Soluble Additives

#### 2.2.1.1 Polymeric Drag Reduction

Polymeric drag reduction is one of the methods of DR where a minute amount of polymer is added in the fluid [2, 6-10, 19, 33, 34]. By adding polymers, the energy from the turbulence of the flow is transferred to the polymers thus DR will happen [19]. It is believed that DR of up to 75% can be achieved by adding polymer [35]. There are also researches that show that the increase in the concentration of the polymer solution decreases the Reynolds stress more [36, 37]. The efficiency of DR also affected by many other factors other than the concentration of DRA. It is found that DR efficiency increases with the increase of temperature, drag reduction agents concentration, flow rate and pipe roughness with the decrease of pipe diameter [38].

Sun et al. used polyacrylamide-based polymer to investigate the DR in microchannel and it is observed that up to 50% of DR is achieved. Greater DR was contributed by higher concentration of polymeric DR at low velocities and large diameter of micro-channel. [39].

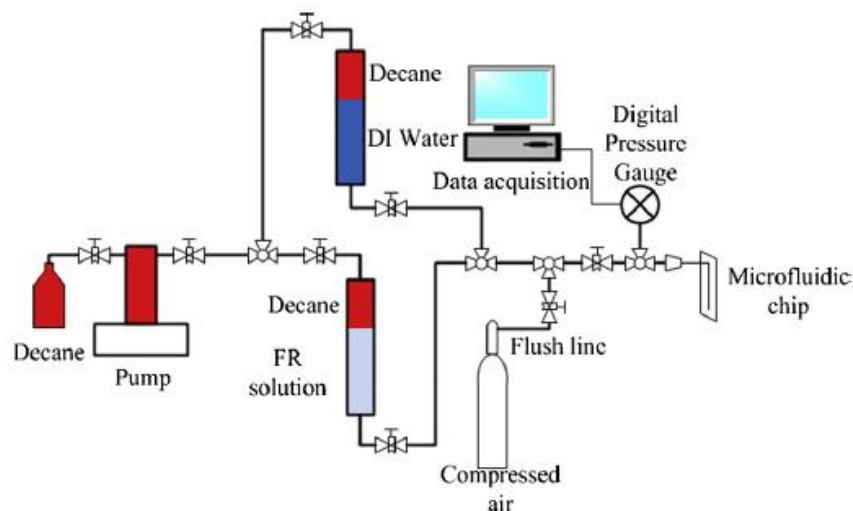


Figure 2-1: Schematic diagram of the experiment for DR using polyacrylamide-based polymer[39]

Tang et al. used polyacrylamide (PAM) solution in three types of different microchannels including fused silica, fused silica square and stainless steel microchannels to investigate the flow behaviours of non-Newtonian fluid. From the experiment, it can be observed that DR is greater in rough stainless steel microtubes than smooth fused silica microchannels [40].

### ***2.2.1.2 Surfactant Drag Reduction***

Surfactant, which produces wormlike micelles, also has the same effect like polymer drag reducing agents to enhance the DR. The strong vorticity fluctuation or formation of eddies near the wall disappears with the introduction of surfactant [12, 41, 42]. Surfactant is suitable for the use of long-term re-circulating heating and cooling system since it has the ability to self-repair after mechanical degradation. Surfactants as the DR agents only receive great attention after the work of Dodge and Metzner [43]. Since then, there are more and more experimental work in this field has been published [11-16, 44, 45].

G. Xia et al. have done an experimental work using 100 ppm Sodium Dodecyl Sulphate (SDS with 95% purity grade) aqueous solution and 300 ppm Alkyl Polyglycoside (APG1214 with 98% purity grade) aqueous solution in a manifold microchannel to study the effect of surfactant on the pressure drop. It is found out that APG is a better surfactant compare to SDS where DR is dependent on the temperature and the velocity of the fluids [46].

A. Ushida et al. used polyethylene glycol (PEG) and surfactant solutions in the experimental study on the DR for the liquid-liquid flow through micro-orifices with the diameter ranging from 5  $\mu\text{m}$  to 400  $\mu\text{m}$ . It is found out that the viscosity of the solutions do not influence the DR. A greater DR is achieved for PEG8000 for 10  $\mu\text{m}$  to 5  $\mu\text{m}$  micro-orifices where DR is almost the same for PEG20000 and PEG8000 for the orifices diameter of 400  $\mu\text{m}$  to 15  $\mu\text{m}$ . In addition, it is found that non-ionic surfactant and cationic surfactant is more effective than anionic surfactants [47, 48].

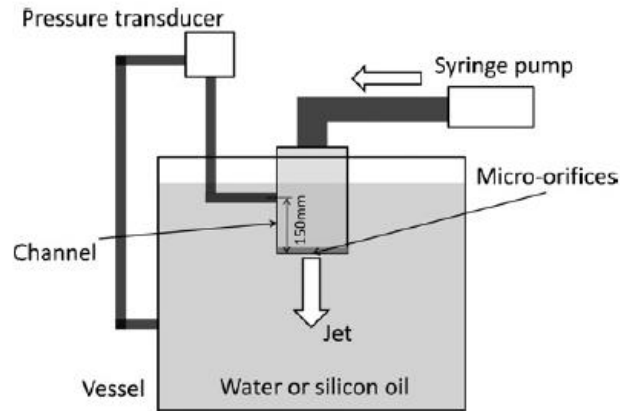


Figure 2-2: Experimental set up for measuring pressure drop for the experiment of DR using polymer and surfactants additives in liquid flow[47]

## 2.2.2 Insoluble Additives

### 2.2.2.1 Nanopowders

Nanofluids, containing nanoparticles suspended in base fluid normally water or organic liquids [49], play crucial role in most of the applications of practical interest [23, 50-52] due to its dispersion quality and stability. However, there is no study has been done on DR using nanoparticle in reducing pressure drop comparing to polymers and surfactants which have been done to an extent in both micro-channels and pipes.

## 2.3 Summary

With the results from those researches or experimental study, public especially for industrial area can understand more on the mechanism and the factors affecting the efficiency of DR. Thus, DR can be applied in the most optimum way. As from mentioned before, it can be clearly seen that there are no studies done on DR using nanopowders. Thus, in this research, experiment on DR using nanopowder as DRA is done in order to have more understanding on this system and thus can be applied in industries to decrease the dependence on pump system hence decrease the consumption cost besides reducing the turbulence and drag inside pipelines.

### 3 MATERIALS AND METHODS

#### 3.1 Raw Materials

##### 3.1.1 Transported Liquid

Deionised water which is obtained from the Chemical Engineering Laboratory of University Malaysia Pahang is used throughout this experiment.

##### 3.1.2 Chemicals

Four types of nanopowders: Bismuth (III) oxide, Iron (II,III) oxide, Titanium (IV) oxide and Silicon dioxide are chosen for this experimental work, which are provided by Sigma Aldrich, considering the hazards of the chemicals. Non hazardous chemicals are chosen since they are more environmental friendly and will not cause harm to other living things. Besides that, size and molecular weight of nanopowders are taking into consideration. The four types of nanopowders chosen are as shown in Table 3-1:

Chemical	Molecular weight (g/mol)	Size(nm)	Density (g/mL)
Bismuth (III) oxide	465.96	90-210	0.5-1.1
Iron (II,III) oxide	251.53	50-100	4.8-5.1
Titanium(IV) oxide	79.87	<100	-
Silica	60.08	200-300	0.037

Table 3-1: The physical properties of nanopowder chosen

#### 3.2 Nanopowder solution preparation

5 different concentration of each nanopowder solution were prepared ranging from 100ppm to 500ppm. Nanopowder solution was initially prepared at the concentration of 500ppm by adding deionised water which will be homogenised in a vortex at 500ml for a few seconds by magnetic stirrer. The solution was agitated on a moving table for 7 hours to achieve dispersion of the nanopowder without breaking the molecules. Before running experiment, the solution was then homogenised by magnetic stirrer at 100rpm for 2 hours. Dilutions were prepared from this solution by adding in deionised water and were stirred again for 2 hours at 100rpm[53].

### 3.3 Equipments

#### 3.3.1 Microchannels

Different types of straight microchannels were used in this experiment to investigate the effect of size of microchannel on DR. Three topas straight microchannel with the width and depth of 50  $\mu\text{m}$ , 100  $\mu\text{m}$  and 200  $\mu\text{m}$  respectively and length of 58.5mm were used.

#### 3.3.2 Syringe Pump

Syringe pump (model: SN-50F6) was used to pump the solution from the syringe into the microchannel by controlling the flow rate of the solution.



Figure 3-1: Syringe pump